MOVEMENT AND ACCUMULATION OF RADIOSTRONTIUM AND RADIOCESIUM IN INSECTS

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INTRODUCTION

The invasion of White Oak Lake bed (Oak Ridge, Tennessee) by insects provided an unparalleled opportunity to investigate the transfer of radionuclides from plants to insects in a terrestrial system. Except in this waste disposal area, the insect components of terrestrial ecosystems have not been investigated as to their position in the accumulation of radionuclides in trophic levels. Most of the work to date on the movement of radionuclides in terrestrial systems has been motivated at least in part by an interest in the food chain leading to man. Terrestrial insects are no longer a significant part of this food chain, but in natural communities they are herbivores of major significance. In aquatic systems, more information concerning the accumulation of radionuclides by insects is available. However, the well-known ability of many aquatic insects to concentrate ions directly from or exchange them with the surrounding medium makes an analysis of food relationships more difficult. These results of insect studies on White Oak Lake bed thus may serve as the only available basis for generalization to other areas which may become contaminated by radioactive wastes.

Concurrent with the invasion of White Oak Lake bed by plant species in 1956, insect associates of these plants appeared and large populations of insects soon developed. Intensive studies of these insect populations were conducted during the summers of 1956-1958, with the following objectives: (1) to determine the extent to which insects would accumulate radiostrontium and radiocesium from their host plants, and (2) to evaluate the influence of insects in the herbivore trophic level upon the redistribution of radionuclides in the lake bed system. In addition, data of a more fundamental ecological nature were gained, both from measurements of the insect populations and from relationships revealed by considering the contaminants as radioactive tracers. Results of these studies have been recently published (Crossley and Howden, 1961). Laboratory and field work during the summers of 1960 and 1961 substantiated the conclusions drawn and make possible some refinements of this previously published work.

METHODS

A detailed account of the methods used has been given previously (Crossley and Howden, 1961). The basic sampling unit for quantitative samples of insects was ten rapid consecutive sweeps with an insect net through the top portion of the vegetation. The sweep-net samples were calibrated against the results from a one square meter box trap, so that the samples could be related to a unit area. Paired samples were taken at weekly intervals in sedge-rush (*Cyperus* spp., *Carex* spp.-*Juncus* spp.) and smartweed (*Polygonum* spp.) areas during August, 1956, June-September, 1957, and at irregular intervals during 1958. One sample of the pair was used for taxonomic purposes; the other served as an estimate of biomass and radionuclide content. In 1961, the basic sample with the insect net was increased from 10 to 50 sweeps to decrease the error in determinations of biomass. Special larger collections were made for estimates of radionuclide concentrations in individual insect species. Gamma-ray spectrometry for cesium-137 and radiochemical methods for strontium-90 were employed.

RESULTS

Insect Numbers and Biomass

Taxonomic collections revealed more than 400 species of insects on the vegetation of White Oak Lake bed during the summers of 1956 and 1957 (Howden and Crossley, 1961). In 1956, both the sedge-rush and smartweed areas contained simple insect communities dominated by one or a few species of insects, but containing many individuals. The diversity of species increased in 1957, but no species was unusually numerous, so that no single species was obviously dominant in 1957. The smartweed disappeared from the sampling areas by 1959, but sedge-rush areas persisted. Samples taken in 1961 showed little change in insect species composition from the 1957 to 1958 samplings, suggesting that the insect communities in sedge-rush areas had become stabilized in two to three years following establishment. The insect communities on these plants appeared normal in that no obvious group of herbivores was absent, nor did unusual host relationships appear.

Table 1. Biomass (milligrams of dry weight per square meter) of insects on White Oak Lake bed vegetation.

	Sedge-rush		Smartweed		Willow	
Year	Sample size	Average[1]	Sample size	Average[1]	Sample size	Average[1]
1956			3	192 ± 38		
1957	22	197 ± 34	22	202 ± 26	22	88 ± 9
1958	6	273 ± 78	6	330 ± 92		
1961	4	83 ± 10				

[1] Average ± one standard error of the mean.

Estimates of insect biomass are shown in Table 1. Willow areas could be sampled appropriately during 1957 only; in subsequent years the willows (*Salix nigra*) were too large for sweep-net samples to be related to a unit area. For sedge-rush and smartweed areas, differences in the biomass estimates for 1957 and 1958 shown in Table 1 probably are not significant. The box trap method, which is more efficient than the sweep-net method, was used more extensively in 1958, so that the 1957 biomass values are probably underestimates. The 1961 samples indicate a marked decrease in insect biomass. These 1961 samples were taken in June; the month was unusually cold and damp, with the result that insect populations were somewhat depressed. Even so, some decrease in insect biomass might be expected. Cross (1956) found that insect biomass decreased during the process of forbs succession in old fields. Estimates of plant biomass in the sampling areas also indicated a decrease from about 600 grams per square meter in 1957 to about 300 grams per square meter in 1961. The proportion of predaceous insects in the biomass samples in 1961 was 0.12, close to the estimates of 0.13 to 0.18 obtained for 1956 to 1958.

Transfer of Cesium-137 and Strontium-90 to Insect Species

In September 1958, large samples of available insect species were collected and analyzed for

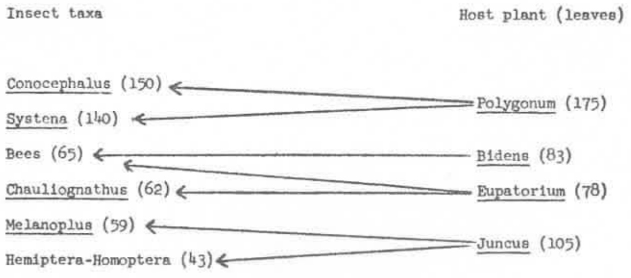

Figure 1. Transfer of cesium-137 from plants to insects. Values in parentheses are micromicrocuries per gram of dry weight of a composite sample. (After Crossley and Howden, 1961).

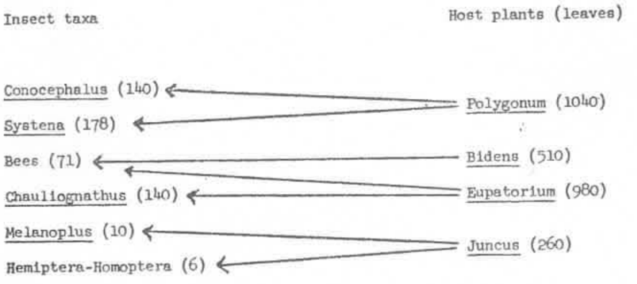

Figure 2. Transfer of strontium-90 from plants to insects. Values in parentheses are micromicrocuries per gram of dry weight of a composite sample. (After Crossley and Howden, 1961.)

cesium-137 and strontium-90. Figures 1 and 2 compare concentrations in insects with concentrations in host plants. The insects feeding on plants with higher concentrations of the radionuclides had higher concentrations themselves. Grasshoppers (Conocephalus) and beetles (Systena) found on smartweed (Polygonum) had the highest concentrations of the radionuclides. Bees (mostly Lasioglossum) on flowers of Bidens and Eupatorium and solder beetles (Chauliognathus) on flowers of Eupatorium were intermediate in concentration, as were their host plants. The lowest concentrations of radionuclides were in grasshoppers (Melanoplus) and Hemiptera-Homoptera (mostly leafhoppers and aphids) found on Juncus. The plant-to-insect transfers resulted in insect concentrations which were about 80 per cent of plant concentrations for cesium-137 and ten per cent for strontium-90. This differential accumulation of the two nuclides seems due to differences in rates of elimination. Strontium was eliminated more rapidly than was cesium from two grasshopper species (Crossley and Schnell, 1961). If this is generally true, the result would be that equilibrium values for strontium would be much lower in insects than values for cesium. The insects feeding on Juncus appeared to accumulate less of the radionuclide content of the plant (50 per cent for cesium-137, three per cent for strontium-90) than did insects on other plant species. In general, however, the concentration of radionuclides in individual insect species appears to be a direct function of concentrations in host plants.

Distribution of Radioisotopes in Trophic Levels

The herbivorous and predaceous insects, the plants, and the soil together constitute a system through which the radionuclides are transferred and in which various steady state equilibria for the radionuclides may be expected. Data collected in 1957 and 1958 are sufficient for a preliminary evaluation of the distribution of strontium-90 and cesium-137 in soil and in trophic levels. Figure 3 shows the concentrations (micromicrocuries per gram of dry weight) of strontium-90 and cesium-137 in organisms belonging to the trophic levels and in soil. Cesium-137 was more abundant in soil than was strontium-90 but was less available to plants (Auerbach and Crossley, 1958), so that strontium-90 concentrations in plants were higher than cesium-137 values. Strontium-90 was concentrated above soil levels in plant leaves. Herbivorous insects contained about equal amounts of the two radionuclides, since strontium is eliminated more rapidly than cesium and equilibrium values thus were much lower than were concentrations in the host plants. Predaceous insects had approximately the same concentrations as did herbivorous insects. Only a few samples of predators were available for analysis; accumulation of radionuclides by predaceous insects on White Oak Lake bed is now under study.

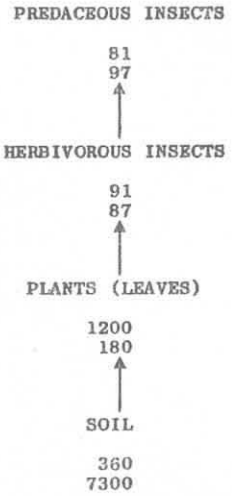

Figure 3. Concentrations of radionuclides in soil and organisms of the White Oak Lake bed, 1958 (upper value strontium-90, lower value cesium-137, in micromicrocuries per gram of dry weight of a composite sample.)

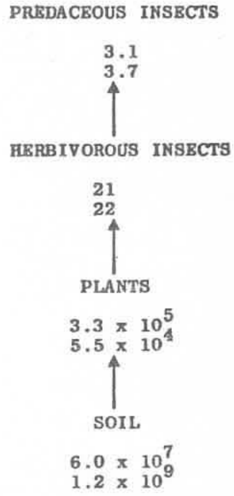

Figure 4. Distribution of radionuclides in soils and trophic levels of the White Oak Lake bed, 1958 (upper value strontium-90, lower value cesium-137, in micromicrocuries per square meter of a composite sample.)

When the actual biomasses of the trophic levels involved are included (Figure 4), reduction in transfer of radionuclides from one trophic level to another becomes the rule. Figure 4 shows the distribution of radionuclides in the soil and trophic levels on a square meter basis. The mass of soil overwhelms the masses of the organisms, so that the soil contained more than 99 per cent of the radionuclides in the system. Data in Figure 4 are based on 1957 collections, when plant biomass was approximately 600 grams per square meter and insect biomass approximately 300 milligrams per square meter. On the basis of biomass estimates in 1961, the plant and insect parts of the systsm would contain even less strontium-90 and cesium-137 than in 1957.

DISCUSSION

In transfer through the food chain, reduction in concentration of strontium-90 and cesium-137 per unit weight (micromicrocuries per gram) was found in movement from soil to insects. However, this does not warrant generalization to other food chains. Neither of the radionuclides involved was concentrated or stored in the tissues of insects. But insectivorous birds on White Oak Lake bed had higher concentrations of strontium-90 than was found in the insects upon which they feed, due to accumulation of strontium in bone (Willard, 1960). The concentration of radionuclides (micromicrocuries per gram) in the food chain will depend upon the average elimination constants or concentration factors in each step involved. When the amounts of radionuclides in the trophic levels are considered (micromicrocuries per square meter), vast reductions occurred during the transfer of radionuclides from one trophic level to another. For terrestrial systems at least, the distribution of radionuclides can be expected to show a decrease (per unit area) in the higher trophic levels. The data in Figure 4 are probably typical in this respect. The magnitude of the values at each trophic level apparently is more dependent upon the masses of organisms than upon the concentrations of radionuclides in the organisms.

Evidently the insects have very little effect on the distribution of radionuclides on the lake bed or in removal of nuclide from the system. In the extreme case, if all of the insects on the lake bed at any one time were to leave, the loss of radionuclides would be about three microcuries each of strontium-90 and cesium-137. For strontium-90, this would be about the amount contained in ten kilograms of soil. While not insignificant, this loss would be relatively quite small. The possibility for the radionuclides to become distributed to other areas or to enter human food chains through the agency of insects seems to be a remote one.

The data in Figure 4 for concentrations in insects do not describe the amounts of radionuclides which pass through the insects feeding on plants. Concentrations in insects rapidly reach a steady state equilibrium, so that the amounts of radionuclides ingested are equal to the amounts eliminated. Insect consumption and passage of radionuclides, then, was much greater than the standing crop concentrations shown in Figure 4. Calculations using the radionuclides in the lake bed system as tracers have provided estimates of the amount of food consumption by insects; these calculations are presented in a separate paper in this symposium. The insects consumed approximately six per cent of the plant biomass during a growing season; thus, about six per cent of the radionuclides in the plants would have passed through the insect trophic levels during a season.

The decrease of plant and insect biomass indicated by the 1961 samples is similar to that noted by Odum (1960) and Cross (1956) for the forb stages of succession in abandoned fields. On White Oak Lake bed, the initial "bloom" of high vegetation and insect production may have been due to the large amounts of nitrates present as a result of the industrial waste disposal operations. Evidently Odum's (1960) contention that a functional equilibrium tends to be established during succession, although community composition continues to change, seems to be supported by these data from White Oak Lake bed. The decrease in plant and insect biomasses, however, would suggest that in 1961 there was less movement of radionuclides from soil into biota, due to reduced production.

SUMMARY

Studies of the insect inhabitants of vegetation on the contaminated White Oak Lake bed measured the transfer of strontium-90 and cesium-137 from plants to insects, and evaluated the accumulation of the radionuclides by the trophic levels involved. Data on accumulation of these radionuclides by individual insect species showed that transfer of cesium-137 from plant to insect tissue was more efficient than transfer of strontium-90 (80 per cent versus 10 per cent). Differences seem due to the more rapid elimination of strontium by insects, with resulting lower equilibrium values. Per gram concentrations showed reductions in movement from soil to insects, with the major reduction occurring in the soil-to-plant step for cesium-137 and in the plant-to-insect step for strontium-90. The magnitude of such reductions is dependent upon the nature of the organisms involved. Transfer through trophic levels in this food chain (concentration per unit area) showed vast reductions at each step, due to the increasingly smaller masses of organisms involved in higher trophic levels.

ACKNOWLEDGMENTS

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